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### 10Kin1day: A Bottom-Up Neuroimaging Initiative

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# 10Kin1day: A Bottom-Up Neuroimaging Initiative

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We organized 10Kin1day, a pop-up scientific event with the goal to bring together neuroimaging groups from around the world to jointly analyze 10,000+ existing MRI connectivity datasets during a 3-day workshop. In this report, we describe the motivation and principles of 10Kin1day, together with a public release of 8,000+ MRI connectome maps of the human brain.

**Keywords: MRI, connectome analysis, diffusion weighted MRI, brain, network**

Ongoing grand-scale projects like the European Human Brain Project (1), the US Brain Initiative (2), the Human Connectome Project (3), the Chinese Brainnetome (4) and exciting world-wide neuroimaging collaborations such as ENIGMA (5) herald the new era of *big neuroscience*. In conjunction with these

major undertakings, there is an emerging trend for bottom-up initiatives, starting with small-scale projects built upon existing collaborations and infrastructures. As described by Mainen et al. (6), these initiatives are centralized around self-organized groups of researchers working on the same challenges and sharing

interests and specialized expertise. These projects could scale and open up to a larger audience and other disciplines over time, eventually lining up and merging their findings with other programs to make the bigger picture.

## 10KIN1DAY

One type of event that fits well with this grass-roots collaboration philosophy are short gatherings of scientists around a single theme, bringing together expertise and tools to jointly analyze existing neuroscience data. We organized 10Kin1day, an MRI connectome event, with the goal to bring together an international group of researchers in the field of neuroimaging and consistently analyze MRI connectivity data of the human cerebrum. We organized the event around five founding principles:

- use existing neuroimaging data, available from many research groups around the world; we focused on diffusion MRI data and aimed to bring together 10,000+ datasets
- analyze data from varying cohorts and imaging protocols, using a single, straightforward analysis strategy to encourage across-group collaborations and multisite studies
- perform all processing during a short workshop, with only basic expertise of analysis needed
- provide education on how to analyze resulting connectome data, so participants can continue to work on their projects after the event
- each participant analyzes their own data and is free to decide what to do with their analyzed results

## THE 10K WORKSHOP

Over 50 participants from 40 different neuroimaging groups gathered in The Netherlands for a 3-day event. Participants brought and worked on their own datasets, varying from MRI data on healthy human brain organization, cross-sectional and longitudinal brain development, aging, cognitive psychology, as well as MRI data of a wide range of neurological and psychiatric brain disorders (including among others: Schizophrenia, Mood Disorders, Alzheimer's Disease, Mild Cognitive Impairment, Amyotrophic Lateral Sclerosis, Frontotemporal Dementia, Epilepsy and Parkinson's Disease). Written informed consent of the included healthy controls and/or patients was obtained by each of the participating researchers at their local institute. 10 TB online storage space and 50,000+ CPU hours was reserved on the Cartesius supercomputer of the collaborative Information and Communication Technology (ICT) organization for Dutch education and research (SURE, <https://surfsara.nl/>) to analyze the data during the workshop. Workshop participants performed data quality checks on their data 1 week before the event after which they uploaded the MRI data (Diffusion Weighted Images (DWI) and pre-processed T1 data, see Materials and Methods) to their own user account on the supercomputer. During the workshop, participants were brought up to speed on DWI processing, connectome construction (see section Materials and Methods for details on the performed analysis), and running parallel jobs on a supercomputer. Together, a total of 15,947

MRI datasets were processed into anatomical connectome maps, with each output dataset including connectivity matrices with different types of connection weights and multiple parcellation resolutions (**Figures 1A,B**). Data processing was paralleled by interactive educational talks and workshops on connectome analysis.

## OPEN DATA

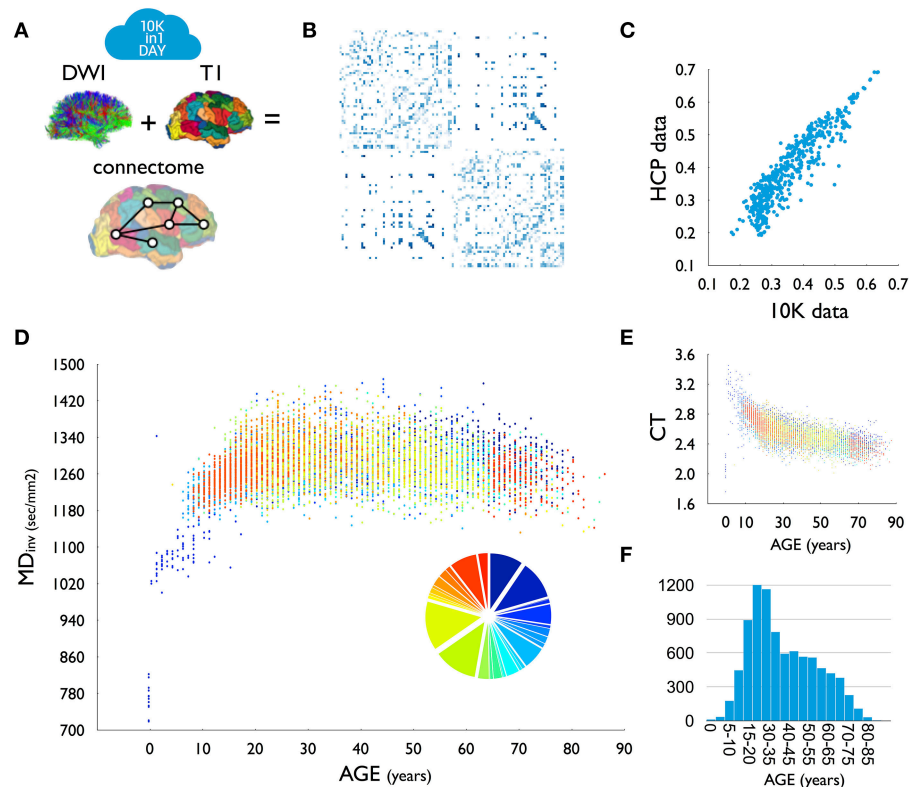
In line with the collaborative nature of the event, the 10K group discussed making the connectome maps available to the scientific community for non-commercial use, free of restrictions. We include herein the resulting individual connectome maps of 8,000+ connectome datasets across an age range of 0–90 years, with five different edge weights [number of traced streamlines (NOS), streamline density (SD), fiber length, fractional anisotropy (FA), and mean diffusivity (MD)] at three parcellation resolutions (80+ cortical and subcortical regions, 100+ and 200+ cortical regions, see section Materials and Methods for details). Connectome maps are presented anonymously and blinded for participation site, together with basic demographics (age in bins of 5 years, gender, patient/control status, **Figure 1**). Data is presented under the Non-Commercial Common Creative (CC BY-NC) license, free for all scientists to use in a non-commercial setting. A download request can be made at [dutchconnectomelab.org](http://dutchconnectomelab.org) for a download link to the data. Data for download includes connectivity matrices with five connectivity weights (NOS, FA, MD, fiber length, SD) at three atlas resolutions, information on the cortical and subcortical nodes, blinded group site and subject demographics (gender, age in 5 year bins, case/control).

## CONCLUDING WORDS

We performed a few first analyses on the joint dataset, including cross-site consistency, comparison to Human Connectome Project (HCP) data and a first examination of effects of age (see Materials and Methods for more detail). We observed a high average consistency across sites with an average cross-site overlap of 92% (sd:0.0251) and a cross-site correlation of FA weights  $r = 0.88$  (sd:0.0958), as well as a high consistency of the 10K group averaged matrix with data derived from the high-quality HCP, with at least 69% of pathways identified in HCP also observed in the 10K set and with 98% of all non-existing connections in HCP verified in the 10K set (**Figure 1C**). Furthermore, the distribution of weights across reconstructed connections is highly similar across the two datasets (FA weights,  $r = 0.93$ ,  $p < 0.0001$ , **Figure 1C**). Age analysis shows clear developmental patterns of cortical morphology (**Figure 1E**) and white matter microstructure across age. Analysis of inverse MD showed rapid growth of microstructure in early years, with continuing development throughout adolescence, peaking around the beginning of the third decade, followed by a steady pattern of decline throughout aging (**Figure 1D**).

We acknowledge that there are many shortcomings to the presented MRI connectome dataset. Besides general, inherent limitations of diffusion MRI (7), the presented dataset is a





**FIGURE 1 | (A)** For each dataset, DWI tractography was combined with T1-based parcellation of cerebral brain regions to reconstruct a brain network. **(B)** Group-averaged (group threshold 33%) FA matrix of the 10K dataset. **(C)** High overlap ( $r = 0.93$ ) between group-averaged FA values as derived from high-resolution HCP data and the 10K dataset. **(D)** Relationship between age and average inverse mean diffusivity (MD, sec/mm<sup>2</sup>) across the 10K dataset. Colors indicate the different included datasets. Insert shows a pie diagram of the size of included datasets, color coded to set participation. One dataset (set\_634413) was excluded from this plot, showing (across the age span) deviating FA (lower) and MD (higher) values than the other datasets (see methods). Due to the high total n, excluding this dataset did not change the relationship with age. **(E)** Relationship between age and average cortical thickness (CT). **(F)** Age distribution of the presented data as in **(D,E)**. T1, anatomical MRI; DWI, diffusion weighted imaging; CT, cortical thickness.

collation of data from a wide variety of groups, acquired with different scanners, different scanning protocols, varying data quality etcetera, and includes data from a mixture of different patient and control populations. While these limitations place constraints on the type of investigations that one can perform with such collated multi-site datasets, we are optimistic that the 10K dataset can be used as a large reference dataset for future studies, enabling many technical and neuroscientific research questions to be addressed (e.g., **Figure 1**). As such, we hope that the presented data will be of use to the neuroscience community in the examination of the human connectome. Above all, we hope that our report will inspire others to organize exciting 10Kin1day-type of events in the near future, bringing together existing neuroimaging data and further catalyze open neuroimaging research of the healthy and diseased brain.

## MATERIALS AND METHODS

A total of 42 groups (52 participants) participated in the workshop, some working on multiple datasets. Each dataset

included a diffusion MRI scan and T1 MRI scan processed using FreeSurfer (8). Datasets across groups included data from 1.5 and 3 Tesla MRI with varying scanner protocols and number of applied DWI gradients. Data included MRI data of healthy participants and patients with a neurological or psychiatric disorder. Twenty-three groups were able to make their data available, making a total of 8,000+ connectome maps publicly available through means of this report. Reconstructed connectome maps are presented anonymously, coded for participation site and disease condition(s). Basic demographics of the datasets are included in the download set.

## DWI Preprocessing

DWI datasets were corrected for susceptibility and eddy current distortions using the open tools from the FMRIB Software Library (FSL, <http://fsl.fmrib.ox.ac.uk>). Depending on their DWI dataset, participants preprocessed their data using the FSL *eddy\_correct* or *eddy* tool. For those DWI sets that included a subset of scans with an opposite k-space read out, an additional field distortion map was formed and applied to the DWI images (9).

## Cortical Parcellation

Before the event, the participants created FreeSurfer files based on their T1 images, with this output being subjected to varying degrees of quality control. The resulting parcellations of the cerebrum were used to select the regions of interest for the connectome reconstruction. The 68 cortical regions of FreeSurfer's standard Desikan-Killiany Atlas (10, 11) as well as 14 subcortical regions were selected as network regions. Additionally, FreeSurfer files were used to further parcellate the cortex into 114 and 219 regions, respectively using the Cammoun atlas (12).

## Fiber Reconstruction

After preprocessing of the DWI data, in-house developed scripts were used to fit a diffusion tensor to the diffusion signal in each voxel of the white matter mask (selected based on the white matter segmentation map of the FreeSurfer files) using robust tensor fitting (13). Simple Diffusion Tensor Imaging (DTI) reconstruction was used due to its robustness and relatively low sensitivity to false positive reconstructions compared to more advanced reconstruction methods (14), and thus potentially being the least distorting solution for connectome reconstruction and analysis based on MR imaging data (15). Decomposition of the tensor into eigenvectors and eigenvalues was used to select the main diffusion direction in each voxel, and to compute fractional anisotropy (FA) and mean diffusivity (MD) (16). Deterministic fiber tractography was used to construct large-scale white matter pathways. Eight seeds (evenly distributed across the voxel) started in each white matter voxel, and fiber streamlines were formed by following the main diffusion direction from voxel to voxel using the *fiber assignment by continuous tracking* (FACT) algorithm (17), until one of the stopping criteria was met. A streamline was stopped when (1) it hit a voxel with an  $FA < 0.1$ , (2) went out of the brain mask, or (3) made a turn  $> 45$  degrees.

## Connectome Reconstruction

A connectome map was made by combining the (sub)cortical parcellation map and the set of reconstructed fibers using commonly described procedures [see (18–21)]. For each of the Cammoun Desikan-Killiany parcellation maps (i.e., 14+68, 14+114, and 14+219 regions, respectively), the total collection of reconstructed fiber streamlines was used to assess the level of connectivity between each pair of (sub)cortical regions, represented as the *connectivity matrix*  $C_{IJ}$ . (Sub)cortical regions were selected as the nodes of the reconstructed network, and for each combination of region  $i$  and region  $j$  where fiber streamlines touched both regions a connection (i.e., network edge) was included in cell  $C_{IJ}(i,j)$  in the connectivity matrix. Five different types of strength of a connection were computed and included as edge strength: (1) the number of reconstructed streamlines (NOS) between region  $i$  and  $j$ , (2) the average FA of the voxels traversed by the reconstructed streamlines, (3) the average MD of the reconstructed streamlines, (4) the average length of the reconstructed streamlines and (5) streamline density computed as the number of reconstructed

streamlines corrected for the average volume of region  $i$  and region  $j$  (18, 19).

## Outliers

A total of 15,947 connectome maps were analyzed across the participating groups. Of the datasets that could be shared, 197 were detected as outliers (and were subsequently removed from the dataset). Outliers were detected automatically by testing per dataset and for each connectome map their average connection strength and their distance to the group average prevalence map. The average connection strength of a connectome map was calculated for each of the five connection weights as the mean of the strengths over all existing (nonzero) connections. To measure the presence of odd connections or absence of common connections in a connectome map, we constructed a group prevalence matrix for each dataset, counting per node pair how many times an edge was observed across the group of subjects in the dataset. For each connectome map the total prevalence of all observed connections and the total prevalence of all non-observed connections was computed. Outliers were identified as connectome maps that displayed on any of the 7 measures (5 weight and 2 prevalence measures) a score below  $Q1 - 2 \times IQR$  or above  $Q3 + 2 \times IQR$ , with  $Q1$  and  $Q3$  referring to the first and third quartile, respectively and  $IQR$  the interquartile range  $IQR = Q3 - Q1$ . This resulted in the detection of 189 outliers in total, which were excluded from the dataset. One complete dataset (set\_634413,  $n=584$ ) showed across all included individual sets an average lower FA / higher MD as compared to the other datasets and this set was excluded from the age curves shown in **Figure 1**. Due to the high overall sample size, including or excluding this dataset did not change the shape of the final plot.

## Cross-Site Comparison

Datasets across sites were compared by computing for each site a group average connectome map (group threshold 60%) and comparing the group average connectivity matrices across each of the sites. Cross-site overlap was computed as the percentage of overlap of the binary matrices and as the correlation between the non-zero elements of the FA group-average matrices.

## Comparison to HCP

To test the validity of the 10K dataset, we compared the group average matrix of the 10K set to the group average matrix of data from the Human Connectome Project (HCP) (3). First, for the 10K dataset, a group average FA matrix was computed, by including those edges that were observed in at least 33% of the group (i.e., a group threshold of 33%,  $> 2700$  subjects showing a particular network edge). Average weight values of the included edges were taken as the non-zero mean of those edges across the group of subjects. Second, a similar group average FA matrix was derived from previously analyzed HCP data (22) ( $n = 487$  datasets). In brief, HCP analysis included the following steps [see (22) for more detailed information on the HCP data analysis]. For each of the HCP DWI datasets a connectome was reconstructed based on the minimally pre-processed data of HCP. Given the high quality of the HCP

data, analysis here included reconstruction of multiple diffusion directions, allowing for the reconstruction of more complex fiber configurations (e.g., crossing fibers) (22). Similarly as for the 10K data, across the total set of 487 datasets, an average FA group matrix was computed, including those network edges that were observed in at least 33% of the total population (i.e., >160 datasets) and taking the non-zero mean of FA values across the group of subjects. Comparison between the 10K set and the HCP dataset was computed by means of (1) counting the number of existing connections and non-existing connections in the 10K dataset as observed in the HCP dataset and (2) by correlating the FA weights of the set of edges as observed in both datasets.

## ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the ethical committee boards of each independent institute. The protocol was approved by the ethical committee boards of each independent institute. Informed consent of all participants was acquired by the independent research groups.

## AUTHOR CONTRIBUTIONS

All authors contributed to the acquisition and/or analysis of the MRI data. MvdH wrote the first draft of the manuscript. All authors revised the manuscript and contributed intellectual content.

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## REFERENCES

- Amunts K, Ebell C, Müller J, Telefont M, Knoll A, Lippert T. The Human Brain Project: Creating a European Research Infrastructure to Decode the Human Brain. *Neuron*. (2016) 92:574–81. doi: 10.1016/j.neuron.2016.10.046
- Insel TR, Landis SC, Collins FS. Research priorities. *NIH BRAIN Init Sci*. (2013) 340:687–8. doi: 10.1126/science.1239276
- Van Essen DC, Smith SM, Barch DM, Behrens TE, Yacoub E, Ugurbil K. The WU-Minn Human Connectome Project: an overview. *Neuroimage*. (2013) 80:62–79. doi: 10.1016/j.neuroimage.2013.05.041
- Jiang T. Brainnetome: a new -ome to understand the brain and its disorders. *Neuroimage*. (2013) 80:263–72. doi: 10.1016/j.neuroimage.2013.04.002
- Thompson PM, Andreassen OA, Arias-Vasquez A, Bearden CE, Boedhoe PS, Brouwer RM, et al. ENIGMA and the individual: Predicting factors that affect the brain in 35 countries worldwide. *Neuroimage*. (2017) 145:389–408. doi: 10.1016/j.neuroimage.2015.11.057
- Mainen ZF, Haussler M, Pouget A. A better way to crack the brain. *Nature*. (2016) 539:159–61. doi: 10.1038/539159a
- Mori S, Zhang JY. Principles of diffusion tensor imaging and its applications to basic neuroscience research. *Neuron*. (2006) 51:527–39. doi: 10.1016/j.neuron.2006.08.012
- Fischl B, Dale AM. Measuring the thickness of the human cerebral cortex from magnetic resonance images. *Proc Natl Acad Sci USA*. (2000) 97:11050–5. doi: 10.1073/pnas.200033797
- Andersson JL, Skare S, Ashburner J. How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging. *Neuroimage*. (2003) 20:870–88. doi: 10.1016/S1053-8119(03)00336-7
- Desikan RS, Ségonne F, Fischl B, Quinn BT, Dickerson BC, Blacker D, et al. An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *NeuroImage*. (2006) 31:968–80. doi: 10.1016/j.neuroimage.2006.01.021
- Fischl B, van der Kouwe A, Destrieux C, Halgren E, Ségonne F, Salat DH, et al. Automatically parcellating the human cerebral cortex. *Cereb Cortex*. (2004) 14:11–22. doi: 10.1093/cercor/bhg087
- Cammoun L, Gigandet X, Meskaldji D, Thiran JP, Sporns O, Do KQ, et al. Mapping the human connectome at multiple scales with diffusion spectrum MRI. *J Neurosci Methods*. (2012) 203:386–97. doi: 10.1016/j.jneumeth.2011.09.031
- Chang LC, Jones DK, Pierpaoli C. RESTORE: robust estimation of tensors by outlier rejection. *Magn Reson Med*. (2005) 53:1088–95. doi: 10.1002/mrm.20426
- Maier-Hein KH, Neher PF, Houde J-C, Côté M-A, Garyfallidis E, Zhong J, et al. The challenge of mapping the human connectome based on diffusion tractography. *Nat Commun*. (2017) 8:1349. doi: 10.1038/s41467-017-01285-x
- Zalesky A, Fornito A, Cocchi L, Gollo LL, van den Heuvel MP, Breakspear M. Connectome sensitivity or specificity: which is more important? *Neuroimage*. (2016) 15:407–420. doi: 10.1016/j.neuroimage.2016.06.035
- Beaulieu C, Allen PS. Determinants of anisotropic water diffusion in nerves. *Magn Reson Med*. (1994) 31:394–400. doi: 10.1002/mrm.1910310408
- Mori S, Barker PB. Diffusion magnetic resonance imaging: its principle and applications. *Anat Rec*. (1999) 257:102–9. doi: 10.1002/(SICI)1097-0185(19990615)257:3<102::AID-AR7>3.0.CO;2-6
- Hagmann P, Cammoun L, Gigandet X, Meuli R, Honey CJ, Wedeen VJ, et al. Mapping the structural core of human cerebral cortex. *PLoS Biol*. (2008) 6:e159. doi: 10.1371/journal.pbio.0060159
- van den Heuvel MP, Kahn RS, Goni J, Sporns O. High-cost, high-capacity backbone for global brain communication. *Proc Natl Acad Sci USA*. (2012) 109:11372–7. doi: 10.1073/pnas.1203593109
- van den Heuvel MP, Mandl RC, Stam CJ, Kahn RS, Hulshoff Pol HE. Aberrant frontal and temporal complex network structure in schizophrenia: a graph theoretical analysis. *J Neurosci*. (2010) 30:15915–26. doi: 10.1523/JNEUROSCI.2874-10.2010
- van den Heuvel MP, Sporns O. Rich-club organization of the human connectome. *J Neurosci*. (2011) 31:15775–86. doi: 10.1523/JNEUROSCI.3539-11.2011
- van den Heuvel MP, Scholtens LH, de Reus MA, Kahn RS. Associated microscale spine density and macroscale connectivity disruptions in schizophrenia. *Biol Psychiatry*. (2016) 80:293–301. doi: 10.1016/j.biopsych.2015.10.005

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